

# Experimental Evaluation of Control Policies for Segway Robot in Dynamic Environments

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ECE 6552: Nonlinear System Project

# Motivation

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# System Description

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# Robotic Platform

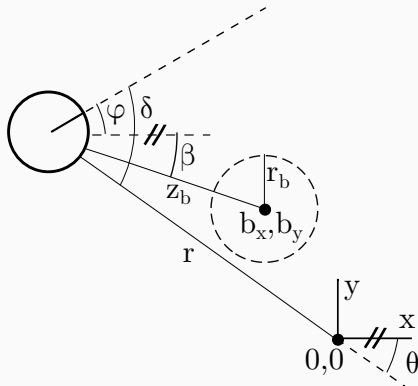


**Figure 1:** Jeeves - A modified Segway based robot mounted with a Primesense, Microsoft Kinect, Roboteye RE05, Hokuyo LTM-30x laser and the UR5. Currently modified to include the casters for static stability

# Unicycle Dynamics

$$\begin{pmatrix} \dot{r} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} -v \cos(\delta) \\ \frac{v}{r} \sin(\delta) \end{pmatrix} \quad (1)$$

$$\dot{\delta} = \frac{v}{r} \sin(\delta) + \omega \quad (2)$$



**Figure 2:** Egocentric Polar Unicycle Dynamics with Obstacle

# Approach

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# Objectives

## Soft Constraints

- Navigate to target location
- Drive the state of the robot to zero (e.g.  $\dot{x} = (\dot{r}, \dot{\theta}, \dot{\delta})^T \rightarrow 0$ )

## Hard Constraints

- Avoid obstacles
- The distance to the obstacle must not exceed a minimum distance (e.g.  $z_b > z_{safe}$ )

## System Constraints

- Inputs should not exceed threshold values
- $0 < v < v_{max}$  and  $0 < \omega < \omega_{max}$



# Approach Overview

A **switched mode** *quadratic programming controller* that **simultaneously** satisfies the soft constraints, hard constraints, and system constraints was designed.

To establish soft constraints as CLFs:

1. Design a steering control that drives the state to zero

To establish soft constraints as CFLs:

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2. Demonstrate that the steering control satisfies the control Lyapunov function

To establish soft constraints as CLFs:

1. Design a steering control that drives the state to zero
2. Demonstrate that the steering control satisfies the control Lyapunov function
3. Design a second steering control that drives the state *away* from zero

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# Soft Constraints as CLFs

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Feedback linearization of this objective by choosing the angular velocity:

$$\omega = -\frac{v}{r} \left[ k_2 z_1 + \left(1 + \frac{k_1}{1 + (k_1\theta)^2}\right) \sin(z_1 + \arctan(-k_1\theta)) \right]$$

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$$\dot{z}_1 = -k_2 \frac{v}{r} z_1$$

$\implies$  *Stabilization of the steering objective*



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$$\dot{V} < 0$$

$\implies$  *Stabilization of the state to zero*

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$$\dot{V} = -rv \cos(\arctan(k_1\beta)) + \theta v \sin(\arctan(-k_1\beta))$$

$$\dot{V} \not\leq 0$$

$\implies$  The second steering control drives the state away from zero





# Results

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# Simulation Results



# Conclusions

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**Questions?**